A SCALE MOUT FACILITY FOR STUDYING HUMAN-ROBOT INTERACTION AND CONTROL

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ABSTRACT

The Human Research and Engineering Directorate (HRED) of the US Army Research Laboratory (ARL) is involved in a 5-year program to understand the implications of introducing new technology and procedures to enhance human robotic interactions (HRI) for the Objective Force Warrior (OFW) and Future Combat Systems (FCS). An important component of the HRI research is the study of the collaborative requirements for human robotic teams. The Team Performance Laboratory (TPL) at the University of Central Florida (UCF) has been contracted to conduct research whose purpose is to understand and enhance the interaction of multiple soldiers with multiple robotic systems that vary in size from small unmanned ground systems (SUGVs), to medium sized unmanned aerial vehicles (UAVs), to six-ton armored robot vehicles (ARVs).

The initial studies will accomplish two objectives: (a) Review the literature and develop preliminary models of multiple soldier - multiple system HRI, and (b) conduct exploratory studies to investigate cost-benefits of various HRI teaming concepts. The current paper describes the practical and conceptual backgrounds for the HRI-research conducted at UCF, and then focuses on a description of the experimental facility created for these studies, i.e., a low-cost scale Military Operations in Urban Terrain (MOUT) facility simulating a section of an Iraqi city. The facility allows the manipulation of variables such as number of operators and robotic assets, operator-to-robot ratios, and external factors such as scenario difficulty, asset reliability, OPFOR units and order-of-battle, as well as the observation and measurement of operator and robot performance in the scenarios. We also describe the initial study currently underway. For this study, data collection will be completed by the end of October 2004.

1. INTRODUCTION

Tele-operated and tele-navigated robotic Unmanned Ground Vehicles (UGVs) are comparably new tools on the battlefield, but they have already been employed in Operations Enduring Freedom (Afghanistan) and Iraqi Freedom (Iraq; Weinberger, 2004). Further, within the next decade, robotic UGVs will increasingly be utilized on the battlefield to augment Airmen, Sailors, Soldiers and Marines (CNN Technology, 2004).

In fact, in 2000, Congress mandated that by 2010, 1/3 of all Army aircraft be unmanned, and by 2015, that 1/3 of all ground combat vehicles be unmanned (National Research Council, 2003). The Future Combat Systems (FCS), the Army's transformation program that focuses on integrating advanced technologies and communications into the armed forces, has led to the utilization of robots, including UGVs and unmanned aerial vehicles (UAVs), for certain tasks that have proven dangerous for soldiers. Specifically, robots are able to perform certain functions, such as mine detection and biological/chemical weapons detection, so that human soldiers do not have to risk their lives. The goal is not necessarily to replace soldiers with robots, but to create teams of soldiers and robots to develop more efficient, adaptive, and cost-effective units that increase combat effectiveness and efficiency on one hand, and reduce the possibility for loss of human life on the other.

1.1 Purpose of the Research

To support the introduction of unmanned vehicles into the Army, it is necessary to conduct research whose purpose is to understand and enhance the interaction of multiple soldiers with multiple robotic systems that vary in size from small unmanned ground systems (SUGVs), to medium sized unmanned aerial vehicles (UAVs), to six-ton armored robot vehicles (ARVs).

The integration of human soldiers and robots, while obviously advantageous, introduces a variety of complex issues into an already complex environment. At the same time, the complexities of the military environment provide unique opportunities for teaming research, as, Urban, Bowers, Monday, and Morgan (1995) pointed out when they stated that "operational military environments provide ideal settings for the development of team performance" (p. 123). Thus, the introduction of human-

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14. ABSTRACT

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robot teams into the Army provides an unparalleled opportunity to study the unique complexities of these newly developed teams in a dynamic environment that already facilitates the study of teamwork. Having an understanding of the unique factors that affect human-robot teams should allow for the ability to design the most efficient teams and to train those teams to perform at optimal levels. However, to gain this understanding, it is necessary to expand and extend previous work on teams and agents, which – in turn – requires the amalgamation of diverse literatures from psychology, sociology, and engineering, specifically literature on teams and on robotics.

While a significant amount of research has analyzed how a variety of factors impact teamwork in all-human teams, little work has focused on teams composed of humans and robots. Only recently has it been suggested that automated systems or technologies might be actual team members, rather than simply resources that the humans must interact with (Hoeft, Kochan, & Jentsch, in press). Furthermore, studies of automation technology, in areas such as aviation and industrial control, have noted a paradoxical increase in the potential for error when emergencies arise in collaborative situations between humans and automated or semi-automated agents. Consequently, there is a need to review the literature on teams, on human performance, on automation, and on robotics to identify what can and what cannot be transferred from all-human teams to mixed human-robot teams.

1.2 Unique Concerns of Human-Robot Teaming

Human-robot interaction (HRI) introduces a number of issues with respect to both team and individual cognition that appear to be distinct from traditional team interactions. Two essential factors of teamwork that will likely impact how human-robot teams operate are interdependence and team coordination. First, interdependence is an important aspect because it is not yet known what the most appropriate team structure or architecture is when it comes to operating multiple robots in coordination with one another. Previous research has shown that varying the levels of different types of interdependence can significantly impact team processes and team performance (cf. Saavedra, Earley, & Van Dyne, 1993). By comparing differing levels of interdependence within the human-robot team, it might be possible to explore this issue of designing the appropriate team for the task.

Second, coordination between team members is important because it dictates whether a team will be able to function as a single unit and accomplish tasks together. Research has demonstrated that high performing teams may adaptively alter their coordination strategies to more implicit modes of coordination during times of high workload (cf. Kleinman & Serfaty, 1989). It is suggested that implicit coordination is a function of team members anticipating one another's needs via shared mental models (Entin & Serfaty, 1999; Kleinman & Serfaty, 1989; Urban et al., 1995). The robotics environment could bring about unique obstacles to developing these shared mental models, and consequently, impact how the team members will communicate and coordinate with one another.

Human-robot teams and teams of multiple humans interacting with multiple robots, create unique teamwork demands. For example, individuals operating in human-robot teams may have to deal with an increased level of abstraction which may place unique demands on their information processing. At the team level, interaction behaviors may become similarly opaque. For example, team coordination traditionally involves the use of explicit and implicit cues interpreted through a shared mental model possessed by the team (e.g., Entin & Serfaty, 1999). In human-robot teams, it is unclear how team coordination proceeds given that differing communication patterns may be necessary to share cues (e.g., in traditional teams, gestures may be used, but in human-robot teams, explicit idiosyncratic communication may be required). Thus, issues relating to team situation assessment processes and resulting team decision making may vary substantially in distributed environments involving spatially separated and heterogeneous teams of humans interacting with robots.

The situation becomes even more complex when multiple robotic UGVs are involved. The requirements for collaboration, cooperation, and teamwork can be presumed to increase dramatically when there is a requirement to control multiple robots simultaneously (Sekmen, Wilkes, Goldman, & Zein-Sabatto, 2003). At the current technological level, most robotic UGVs are operated via tele-operation. The operators are assisted by visual displays showing the state of the robots, sensor views (usually TV camera images) from the robots, and, in the future, by a dynamic simulation that models the current state of the robots in order to predict potential mission outcomes. Commands are then transmitted to the robots to change their goals, operating states, and/or their control rules. The control team also intervenes when unexpected situations occur. While some robotic UGVs can already follow a set of simple rules based on local sensory inputs, the future is one of less tele-operation and more supervisory control of semi-autonomous and autonomous vehicles.

Both technical (e.g., bandwidth) and operational (e.g. security) concerns dictate that a minimum of explicit communications among team members operating multiple robots are employed. Consequently, since implicit coordination seems to reduce the need for explicit communications, it appears a desirable goal in teams operating multiple robots. However, at this time we do not know whether the human-robot team environment is conducive to implicit coordination nor how this phenomena might be affected by different levels of interdependence among team members, both human and robot.

1.3 Year 1 Approach

The TPL approach to the study of human robotic teams focused in Year 1 on (a) reviewing the literature and developing preliminary models of multiple soldier - multiple system HRI; and (b) conducting exploratory studies to investigate cost-benefits of various HRI teaming concepts. Overarching the research was the need to develop and use test beds and simulations. This was based on the following assumptions:

a. We focused specifically on teams of human operators and semi-autonomous and tele-operated robotic UGVs. We conducted our Year 1 investigations with a focus on UGVs, as these are (a) relatively straightforward to simulate (see below) and (b) most relevant to the U.S. Army's future missions.

b. We developed test beds/simulations that allow the study of the entire range of control operation, i.e., from tele-operation (e.g., MULE, Packbot) via supervisory control of semi-autonomous vehicles (ARV, SUGV) to supervision of autonomous vehicles (SUGV).

c. We developed test beds/simulations that allow the study of control from both a mounted crew station and a dismounted Objective Force Warrior (OFW).

d. Extensions to uninhabited aerial vehicles (UAVs) and unmanned maritime vehicles (UMVs) will be possible in later years.

In Year 1, we developed and built a test bed that employs a low-cost, scale simulation environment using actual vehicles. Under this approach, commercial, off-the-shelf (COTS) remotely/radio-controlled vehicles have been modified with cameras and simulated weapons systems. These assets are controlled by the study participants who are fulfilling the roles of the vehicle controllers. Semi-autonomous features are simulated by study participants expressing their intent for the control of the vehicles, which then are translated into the robots' actions by confederate participants in a separate control room. The confederates act in accordance with specified rule sets that imitate the semi-autonomous or autonomous actions of vehicles such as the MULE platform, the ARV platform, etc. The rule sets incorporate, for example, turning directions when encountering obstacles, coordination with other vehicles, etc. These maneuvers are executed by the confederates when encountering the triggering conditions.

At the same time, test participants playing the roles of UGV controllers are unaware that the vehicles' autonomous or semi-autonomous behaviors are only imitated by confederates. By changing the rule sets that the confederates follow, we are able to quickly "reprogram" the robots and in fact are able to simulate even complex behaviors currently technically difficult to achieve in today's UGVs. Consequently, the vehicles appear to the test participants as bona fide robots; yet, at a much lower cost than the use of actual UGVs would entail. Thus, using relatively simple and inexpensive technology, supported by "man-behind-the-curtain" technology, we are able to study the impact of a large number of variables on teamwork, control requirements, and mission performance.

2. DESCRIPTION OF THE FACILITY

The scale MOUT facility is built to 1:35 scale and covers an area equivalent to 250 m x 180 m which is comparable in size to the action areas in Mogadishu during Operation Restore Hope and in An-Nasariyah during Operation Iraqi Freedom. Through the use of meandering streets, visual obstructions such as buildings, palm groves, etc., effective mission distances of between 1 and 3 km can be achieved, which is comparable to the distances demonstrated in the XUV Demo III program at Ft. Indiantown Gap, PA (Schipani, 2003). COTS vehicles and figures are used to simulate opposing forces, friendly forces, third-party actors, and civilians (see Figures 1, 2, and 3).

Figure 1. Image of the UCF/TPL scale MOUT facility for studying Human-Robot Interaction.

Figure 2. Detailed 1/32 and 1/35 scale figures are used to provide study participants with a rich, relevant, and realistic set of visual cues.

Figure 3. Different sections of the MOUT facility represent different sections of terrain and urban development. Pictured is an Oasis in the desert section of the facility.

In addition to the physical facility itself, we also employed other avenues to create a sense of realism and fidelity. Specifically, maps of the MOUT facility layout were created by consulting existing maps of Iraq and the city of An Najaf. By using photo-editing software, we were able to develop a quadrant map of our specific location and then to incorporate that subsection into the actual existing map. Figure 4 shows a wide view of the existing map of An Najaf with the UCF/TPL scale MOUT facility embedded into it as if it actually was a real portion of the city. A variety of different maps were used to create multiple views of the sector to provide the participants with additional resources and facets of realism.

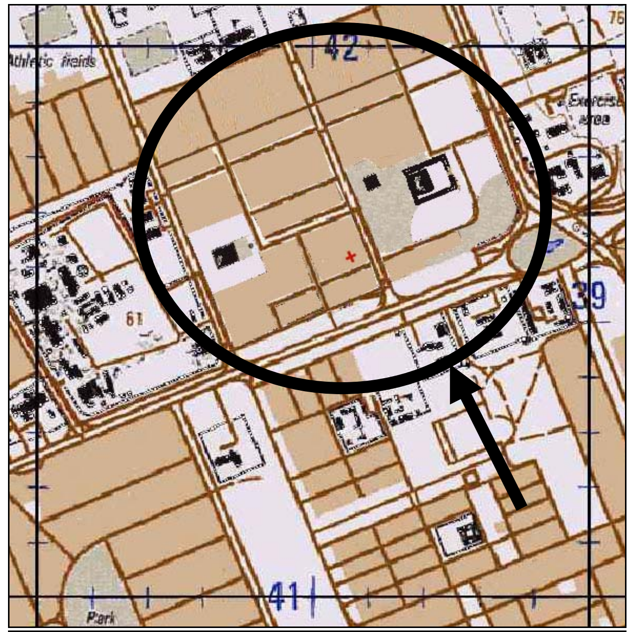

Figure 4. Sample map of the current layout of the UCF/TPL scale MOUT facility embedded in an existing map of An Najaf.

Finally, multi-media stimuli, such as audio cues representing battle noises, the calls of the muezzins to prayer at the Mosques, and popular Arabic music in the marketplace provide a multi-sensory and more immersive experience to the study participants.

3. GENERAL METHODOLOGY

3.1 Participants

Participants are second-year and third-year ROTC cadets from the UCF Army ROTC detachment. Participants are randomly assigned to the appropriate between-subjects conditions.

3.2 Scenarios

In the scenarios, one or several tele-operated Armored Reconnaissance Vehicles (ARV-A) are on Reconnaissance, Surveillance and Target Acquisition (RSTA) missions in the scale MOUT environment. The missions for the ARV-A(s) are developed to reconnoiter the area and identify, map, and report the location of enemy assets, such as SAM and SSM launchers, bands of insurgents, etc., and then to withdraw back to the start line. Each scenario run takes about 20 minutes. Figure 5 shows a sample mission map for Mission Anaconda which includes phase lines and objectives for the specific task.

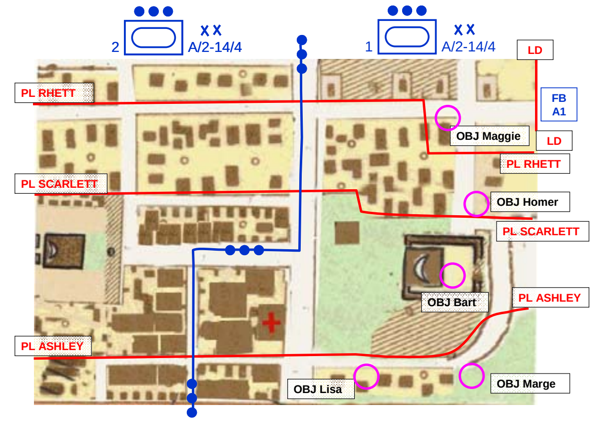

Figure 5. Sample mission map with graphic control measures, objectives, etc.

3.3 Procedures

All participants are being trained on the operation of the vehicles and sensors. They then perform the appropriate number of scenarios, counterbalanced in order across participants and conditions. Together with orientation, training, and the scenarios, each participant participates in one session of approximately 2 to 2 ½ hours duration. All scenarios, including sensor views, operator actions, and operator communications are video- and audio-taped.

3.4 Measures

Dependent measures are taken at two levels. Measures of Performance (MOPs) that can be obtained in the facility include:

- time to map the target area (negative)
- percentage of area covered multiple times (negative)
- time exposed to enemy fire (negative).

Measures of Effectiveness (MOEs) include:

- percentage of targets acquired accurately (positive)
- percentage of false alarms (negative)
- number of false assignments of friendly assets (i.e., precursors to incidents of fratricide) (negative).

Also measured are Individual Differences Variables for each operator, including:

- spatial ability, using two sub-scales of the Guilford-Zimmerman Spatial Aptitude test
- declarative and procedural knowledge in military operations in urban terrain, using a multiple choice test
- structural knowledge of the task, procedures, and vehicle behaviors and capabilities, such as accuracy and sharedness of mental models measured by card sorts and concept maps completed through the TPL-KATS computerized structural knowledge measurement software (see Hoeft, Jentsch, Harper, Berry, Bowers, & Salas, 2002)
- workload perceptions, using the NASA Task-Load Index (TLX) measurement scale.

4. DESCRIPTION OF STUDY 1

In our initial study, we are studying the influence of task difficulty and asset reliability on operator performance when controlling one or two vehicles alone or together with another operator. The design for the study is a 2 x 2 x (2 x 2) mixed-model design. The between-subjects variables are (a) the number of operators (one vs. two) and (b) system reliability (low vs. high). The within-subjects variables are (c) task difficulty (low vs. high) and (d) number of vehicles to control (one vs. two). Task difficulty is manipulated through changes in external scenario factors, such as the number and type of obstacles or enemies. System reliability is manipulated through the introduction of selected failures, specifically in command execution (e.g., vehicle does not respond to a command) and information transmission. Initial results suggest that

5. CONCLUSIONS

According to MacMillan, Paley, Levchuk, Entin, Freeman, and Serfaty (2001), rapidly evolving technology is a contributing factor to the need for “more rapid and efficient ways to create team structures that take maximum advantage of the capabilities of technology for accomplishing mission goals” (p. 284). Additionally, they suggested that the introduction of technology both alters the nature of tasks that must be performed by team members and changes the way in which team members communicate with one another. Both MacMillan et al. and Schraagen and Rasker (2003) suggested that teams can be designed to fit the task by taking into account specific aspects of the task such as each person’s role, the nature of the interdependencies, the structure of the team, necessary coordination and communication, and the level of workload to be experienced.

One of the most vexing questions facing researchers and practitioners who want to use simulation-based research to study and train Human-Robot-Interaction (HRI) is the manner and degree to which the physical environment of the simulation must approximate the real physical characteristics of the world in the transfer environment. Termed “physical fidelity,” this variable is distinct from another form of fidelity, specifically functional fidelity, which describes the degree to which things and processes in the training environment “function” as they do in the transfer environment.

Early on, researchers postulated the utility of creating a simulation environment of high physical fidelity to facilitate learning and transfer of training (e.g. Thorndike, 1931; Osgood, 1949). Thus, when simulators and simulations were increasingly used in aviation and transportation in the 1960s and 1970s, physical fidelity of the environment became a major concern.

Terrain models (i.e., physical scale models that represent real world environments) had long been used for war games and military practice. They allowed the representation of the world under controlled conditions, and – when paired with TV-cameras that could project a view of the scaled world to the trainee – they became the logical choice for simulation-based training in many domains. Before the advent of high-powered computers which could create dynamic graphics, terrain models provided the most realistic representations of "real-world" scenarios that resources and technology would allow. Consequently, an entire generation of pilots and vehicle operators were trained using terrain models.

By the late 1970s, however, innovations in computer technology and concomitant affordability spurred an increased focus on the use of computer-generated (i.e., synthetic) environments for simulation and training. Computer simulations provided a synthetic world that could provide realism and flexibility for creating and manipulating environmental parameters. Training in computer-based simulations quickly proved to be efficient and effective (Caro, 1988).

In the 1990s and the early years of the new millennium, computer simulations have continued to develop into a level of unparalleled sophistication. There are obvious advantages for utilizing this technology; (a) objects and features, once modeled, can be replicated manifold at low cost, (b) physical constrictions of space and scale that limit the attainable size of terrain boards do not exist, and (c) environmental changes (such as precipitation, fog, lighting, etc.) can be introduced quite easily into computer simulations.

However, there are also major drawbacks in the use of computer-based simulation environments. Two very relevant issues in this regard are the increasing cost and time that are required to create these more sophisticated computer environments. Software for simulations of high physical fidelity is very complex and often proprietary, and even small changes require the use of experienced and highly-skilled programmers. Further, specifically in military simulations stemming from the Cold War, many of the physical features of today’s world of low-intensity conflict have not been modelled. For example, while military simulations may include detailed physical and behavioural models of armed forces, they frequently include little to no civilian populations, vehicles, and situations.

More affordable PC-based computer simulations, on the other hand, have shown utility for developing certain skills (e.g. Jentsch & Bowers, 1998), but they may not provide the level of physical fidelity or allow the degree of manipulation needed for modern day training goals. For example, a game-based tank simulation may include realistic objects such as houses and people, but when the trainee drives into a house in the virtual world, the vehicle either drives right through it or stops. This can give a false sense of security because, in the real world, the trainee would actually kill the person in the former case or severely damage the structure in the latter.

In other words, computer-generated simulations have become split into two categories, each with its own weaknesses: The “high-end” simulations may be so sophisticated that they are too costly and time consuming to modify, whereas the “low-end” ones do not provide the degree of fidelity necessary for effective training.

In summary, practitioners and researchers who want to study human-robot interaction and teaming must choose approaches to creating physical fidelity in simulations in a manner that considers how to best attain their objectives (Salas, Bowers, & Rhodenizer, 1998). In this context, computer-generated synthetic environments may not always be the most appropriate tool in HRI simulations. On the one hand, high-end simulations have become increasingly sophisticated, costly, and time consuming to develop. More affordable computer simulations, on the other hand, may lack the fidelity necessary for effective training of skills and transfer of training to the job environment.

The TPL scale MOUT facility for HRI research integrates a scale world terrain board with new and affordable equipment. This provides the high physical fidelity of expensive computer simulations, yet at a much lower price. In the coming years, we believe we will be able to derive results from the experimentation in the scale MOUT facility that will have a direct impact on the war fighter’s ability to interact with and successfully employ unmanned and robotic assets. Finally, we believe that this old, yet also new, technique could be applied to other sectors where research and training in an environment of high physical fidelity is critical.

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